THE DISPLACEMENT OF THE GRAVITATING NEEDLE IN ITS DEPENDENCE ON ATMOSPHERIC TEMPERATURES

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Communicated October 8, 1919

1. Introductory.—In *Science* (**50,** pp. 214, 279, 1919) I communicated some of the early results, showing that the deflection of the needle of a gravitation apparatus varies in marked degree with the temperature on the outside of the building. I have since carried these experiments on for another month and the evidence has become more definitely interpretable. The work was done in a semi-subterranean room, in which the thermostat shows temperature variations which do not usually exceed a fraction of a degree. The room is large and so damp that all electrical excitation is excluded. Tests with radium fully confirmed this. Moreover the room is kept dark. The apparatus (PROCEEDINGS, **4,** p. 338, 1918) placed on the north-south wall of the pier confronts an eastern 30-inch wall, at a distance of about 4 meters and the outside of this is illuminated by sunlight, if present, in the morning, only.

2. Observations.—The observations during July and August are given at the bottom of the figure, the two curves being mean results of the a.m. and p.m. readings, respectively. The telescopic reading of the scale is y, so that Δy denotes the mean (static) excursion or double amplitude, when the attracting mass, $M = 1$ kgm. is passed from one side to the other of the attracted shot ($m = 0.6$ gram), at the end of a needle suspended by a quartz fiber. The actual excursion of the shot is $\Delta x = 0.01455\ \Delta y$, so that the magnification is about 70. The figure shows that even these mean excursions vary enormously, from values much below $\Delta y = 2$ to values above 7, easily five times. If individual excursions were taken, ratios as high as 10 might be found, in spite of the practically constant room temperature. On the upper part of the chart I have inserted the temperature observations θ in degrees F., made at Providence by the United States Weather Bureau, as well as the temperature variations $\Delta\theta$ (high minus low) of the successive days of the months, the same abscissas holding for all curves.

In the earlier data there seemed to be a close association between the Δy and θ curves. In the present data the regions a, b, c, d, e, belong

together, though the Δy curve follows the θ curve with a lag of one or more days. A far better agreement in sense, not quantitatively always, now appears between the Δy and $\Delta\theta$ curves, and here in the given time scale, practically without a lag. To bring this to the eye more clearly, I have indicated the corresponding successive cusps in both curves with the same numbers 1 to 23. The agreement is in fact as close as it can possibly be, remembering that $\Delta\theta$ holds for twenty-four hours of the day and Δy only for the daylight interval of observation. In the same way the a.m. and p.m. curves differ enormously when there is sunlight, and very little in damp cloudy rainy weather (R in curve). In general

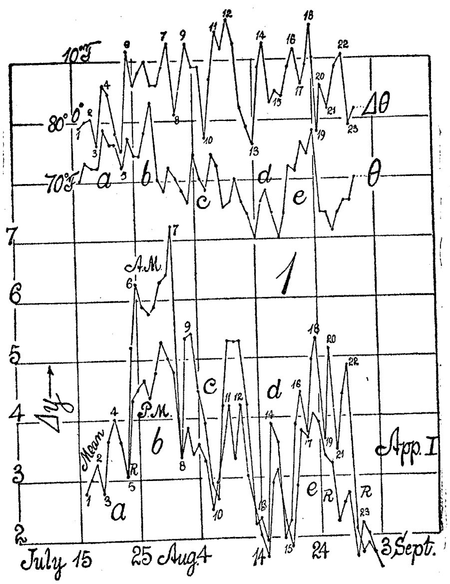

FIG. 1

and apart from details, the a.m. excursions reappeared in a subdued form in the p.m. results.

3. *The needle in vacuum.*—In *Science* I also communicated a series of results since much amplified, showing that for a case of two glass plates spaced by an impregnated wood frame, the initial attractions could be diminished to about one-third of their value by exhausting the case. The excursions diminished with the pressure, at a mean rate of 1%, per mercury centimeter of pressure. The glass plates in this case were about 1.8 cm. apart, inside. In case of the plenum the general character of the a.m. and p.m. excursion did not essentially differ from the graphs for apparatus I.

With the object of gaining some insight into the remarkable behavior at low pressure a new apparatus (no. III) was constructed with the glass plates spaced by a rectangular frame made of square brass tubing. The inside distance between plates was here 1.3 cm.; but in other respects it closely resembled the wood frame specified. The results with this metal case, however, differed totally from those of the other. In the morning of a bright day, there was usually marked repulsion between M and m, which changed gradually into an attraction at the close of the day. The repulsion was often so strong that the ends of the needle were pushed up into contact with the glass plates, to which position they returned whenever removed by tapping.

It was found, however, that the needle could be immediately freed by exhaustion of the case. In other words the repulsions passed continuously into attractions which were here at their maximum at the highest

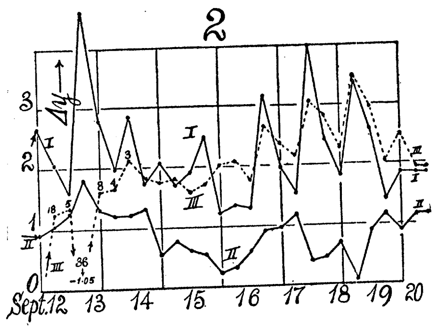

FIG. 2

exhaustions. The behavior of the metal case was thus the reverse of that of the wood case. In the former exhaustion removed a repulsion; in the latter, an attraction. It is difficult to assign a reason for this as there are three forces in contention: viz., gravitation and the radiant forces of the case (static) and of the external mass M. One is tempted to contrast the non-conducting wood with the conducting metal. The greater narrowness of the frame of the latter, however, gives the forces due to temperature distributions an advantage. In one respect the exhausted metal case has shown marked superiority; at a definite high vacuum, the excursions of the needle on any day are without drift; they are nevertheless variable on successive days. It is thus also improbable that this vacuum excursion corresponds to the gravitational attraction, so that an adequately trustworthy excursion is yet in arrears.

4. *Record of the vacuum needle.*—To exhibit these relations more clearly I have constructed figure 2, which contains a record of mean

results for three different apparatus, observations on the same vertical being made at the same time. The individual observations were taken thirty minutes apart Three or four means were deduced for the day. Apparatus I on the N.S. face of the pier fronting East has already been referred to in connection with figure I. Apparatus II was placed in a niche on the EW. wall of the pier fronting north, surrounding *on all sides* within 1 meter by the interior brick walls of the building. It thus receives secondary radiation only, and the graph in its details, departs utterly from curve I, particularly on clear days. If curves I and II were smoothed, however, they would show some resemblance.

Curve III are the results for the metal case (on the E.W. wall fronting south) with the needle kept in the partial vacuum, pressure p, marked on the curve. On the morning of September 12 and 13 at 39 and 36 cm. the two bodies M and m repelled each other. Even at lower pressures (p = 8, 5, 3, etc.) the results seemed fluctuating. Hence after September 14, I observed for $p < 1.5$ c.m., only (numeral omitted), there being a slight leak in the apparatus so that a higher vacuum could not be held for a half hour. The astonishing feature of these high vacuum (III) results is that they agree very closely with the observations (I) made in a plenum; whereas if III had also been observed in a plenum, the results would necessarily be in total opposition to I, as the repulsions at the beginning of curve III indicate.

Now it may be shown by direct tests (*Science*, l.c.) that the radiant forces of a hot body, M are repulsions for $p < 4$ cm. and attraction for higher pressures in the case. The exact pressure of radiant equilibrium resulting from this inversion is for incidental reasons difficult to specify; but one may estimate that in high vacua, y varies about 5 mm. per cm. of pressure p.

It follows from this that in the plenum apparatus (I) with eastern exposure, the attracting body M must be relatively warm in the morning and cold in the afternoon; while in the vacuum apparatus (III) with southern exposure, the body M is relatively cold in the morning and warm in the afternoon; for in such a case the radiant forces have the same sign. Hence the agreement in kind of the plenum graph, I, and the vacuum graph, III, in figure 2, after September 14, is a demonstration in a dark room, at practically constant temperature, of the rotation of the sun.

[1] Advance note from a Report to the Carnegie Institute of Washington, D. C.